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An Evaluation of Alternative Measures of Expected Inflation

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This study evaluates the performance of three alternative measures of inflationary expectations in the context of the investment sector of a structural econometric model of the U.S. economy. Overall, the evidence suggests that actual expectations of inflation are close to being purely autoregressive, depending only on current and past inflation itself. Survey measures of expectations, which potentially might contain more forward-looking and "rational" elements, generally do not have any more explanatory power than other measures. Also, purely autoregressive measures remained a good representation of actual expectations of inflation even when monetary policy was changing sharply in the post-October 1979 period of disinflation.

Accurate forecasting of the response of the economy to changes in monetary policy requires an accurate modeling of the public's expectations of inflation. Conventional macro-econometric models typically incorporate relatively backward looking and slowly adjusting expectations of inflation. Critics stress that these models usually omit information about past values of other variables, such as the money supply, and also information about how monetary policy is likely to respond to the state of the economy in the future. Moreover, backward looking models of inflationary expectations tend to produce systematic forecasting errors, which economic agents might be expected to correct. In view of these criticisms, Robert Lucas (1976) has stated:

> "The long run implications of current forecasting models are without content, and the short-term forecasting ability of these models provides no evidence of the accuracy to be expected from our simulations of hypothetical policy rules."

In contrast, Lucas holds to the view that the inflationary expectations of economic agents in all markets tend to be fully "rational" in the sense that they are unbiased forecasts of future inflation. If this is the case, monetary policy is not able systematically to affect either real interest rates or output and employment.

On the other hand, many economists believe that the condition of full rationality assumes too much about the knowledge of economic agents. The assumption of full rationality requires that economic agents know the "true" model of the economy and make unbiased estimates of its parameters. Furthermore, full rationality assumes that economic agents know how policy affects the economy and even what policy rules will be followed by the government in the future. Given the inherent uncertainties about such things, a model that gradually adjusts inflationary expectations according to recent experience may be an adequate representation of the best that economic agents are able to do. Reflecting this view, Otto Eckstein (1981) said:

> "The data tell us that it takes workers, investors, and businessmen several years to accept conditions of inflation or output growth as permanent. . . The rational expectations school needs to specify the learning process by which information enters decisions

explicitly, particularly how individuals form permanent expectations from temporary data and how they modify their behavior to changes in the economic structure."

To shed some light on the appropriate way of modeling inflationary expectations, this article evaluates the performance of three alternative measures of inflationary expectations in the context of the investment sector of a structural econometric model of the U.S. economy. This model is used for forecasting and policy simulations at the Federal Reserve Bank of San Francisco.[1] The three alternative measures of expected inflation are: 1) a purely autoregressive measure that depends only on current and past values of inflation; 2) an "augmented" autoregressive measure that depends as well on current and past values of other variables that determine the inflation rate in the San Francisco model; and 3) a survey-based measure that potentially might contain more forward-loooking information than either of the other two measures. While the tests necessarily are joint tests of both the model's specifications and the measurement of expected inflation, taken together, the results provide useful evidence on the nature of actual inflationary expectations.

Agents in different markets may have access to different sets of information and incur varying costs of collecting such information. Also, arbitrage may force rapid adjustments to new information in some markets but not in others. As a result, different measures of inflationary expectations may be appropriate in different markets. We therefore examine the explanatory power of the three different measures of expected inflation in three different areas of the investment sector of the structural econometric model: consumer durables, the Aaa corporate bond rate, and nonresidential fixed investment.

Overall, the evidence suggests that inflationary expectations in the investment sector of the economy tend to be relatively backward-looking and adjust only gradually to new information. Survey measures of expectations, which potentially might contain more forward-looking and "rational" elements, generally do not have greater explanatory power than the other measures. Except in the bond market, where past values of variables other than inflation do have some significance, the actual formation of expectations of inflation generally appears to be purely autoregressive. Finally, the purely autoregressive measures remained good representations of actual inflationary expectations even when monetary policy was changing sharply in the post-October 1979 period of disinflation.

In section I, we develop the three alternative measures of short-term inflationary expectations and compare their relative forecasting accuracies. Since the concern in this paper is not with forecasting accuracy, but with accurate representations of the way expectations are formed, Section II uses these measures to estimate corresponding real short-term interest rates and then compares their explanatory powers in the equation for consumer spending on durable goods. Section III develops three alternative measures of long-term expectations of inflation and tests their explanatory power in an equation for the corporate bond rate. Section IV tests similar measures of long-term expectations of inflation in equations for business investment in structures and equipment. A summary and conclusions are provided in Section V.

I. Alternative Measures of Short-Term Expectations of Inflation

In this section, we develop the three alternative measures of expected inflation over a short-term forecasting horizon of two quarters ahead, and then compare their relative forecasting accuracies. These measures of expected inflation are then used in the next section to estimate the real 6-month commercial paper rate.

Purely Autoregressive Measure

In his pioneering studies of the effect of expected inflation on nominal interest rates, Irving Fisher (1930) used simple autoregressive measures of expected inflation that depended on only current and past inflation. Phillip Cagan (1956) subsequently developed a theoretical rationale for imposing geometrically declining weights on the past values of inflation in his hypothesis of adaptive expectations. Although rationales for more flexible lag patterns and techniques for their estimation have been developed since then, Cagan's adaptive expectations hypothesis has been widely used as an autoregressive representation of expectations.[2]

According to this hypothesis, economic agents revise expectations of inflation ($\dot{p}^e$) from one period to the next in proportion to the difference between the actual inflation rate ($\dot{p}$) in the most recent period and the rate of inflation the had been expected.

$$\dot{p}^e - \dot{p}^e_{-1} = \alpha(\dot{p} - \dot{p}^e_{-1}) \qquad (1)$$

Collecting terms, the adaptive expectations hypothesis says that the current expectation of inflation is equal to a weighted average of current inflation and the most recent expectation of inflation.

$$\dot{p}^e = \alpha\dot{p} + (1 - \alpha)\dot{p}^e_{-1} \qquad (2)$$

The coefficient of adjustment, α, determines the weight economic agents put on new information about inflation. Solving this equation recursively, we obtain:

$$\dot{p}^e = \sum_{i=0}^{\infty}\alpha(1 - \alpha)^i\dot{p}_{-1} \qquad (3)$$

In the current context, $\dot{p}^e$ is interpreted as the expectation of inflation for two quarters ahead, and $\dot{p}$ is the quarterly rate of inflation in the GNP fixed weighted price index. The speed of adjustment, α, is estimated at 0.2 from the equations in the San Francisco model containing the real 6-month commercial paper rate.[3] The lag was truncated at 31 quarters, at which point the lag weight became trivially small. Because $1>\alpha>0$, the sum of these weights on past inflation equals one; and $\dot{p}^e$ ultimately converges to any steady actual rate of inflation. When inflation is rising, however, the adaptive expectations model systematically underestimates inflation; and when inflation is falling, it systematically overestimates. A criticism of the adaptive expectations hypothesis is that such errors potentially are correctable.

Augmented Autoregressive Measure

A more sophisticated measure of expected inflation can be derived from the inflation equation in the San Francisco econometric model. This equation collapses wage and price determination into one. The equation is an expectations-augmented Phillips curve, with inflation being determined as a function of the unemployment rate, past inflation, and variables that capture the direct effects of shocks to the price level from changes in the real price of oil and the real value of the dollar. Past inflation enters in the form of a polynomial distributed lag. In this augmented specification, past inflation captures not only inflationary expectations in the labor market, but also the effects of lags introduced by the contracting process.

Given past inflation, the current rate of change in wages, and hence prices in this equation, is assumed proportional to the excess demand for labor.[4] The presence of excess demand for, or excess supply of, labor implies that the adjustment to equilibrium does not occur instantaneously. The slow convergence to equilibrium in this model is appropriate because the labor market is not organized as an auction market.[5] Furthermore, because of an inverse relationship between vacancies and unemployment, the unemployment rate can be used to measure excess demand for labor.[6] Since the sum of the estimated coefficients on past inflation is not significantly different from one, we constrain them to that value. This implies a vertical long-run Phillips curve in which the rate of inflation at full employment is equal to the rate of inflation inherited from the past. It also reflects the view that excess demand, corresponding to an unemployment rate below the full employment level, leads to a continuous acceleration in the inflation rate.

The GNP fixed weighted price index that we use for the measure of prices does not include prices of imports. However, changes in import prices that are brought about by changes in the real value of the dollar indirectly influence prices of domestically produced goods. In purely competitive product markets for homogeneous goods such as agriculture, the "law of one price" suggests that changes in the price of imports due to real exchange rate changes will be fully passed through to domestic producers. In markets for non-homogeneous products, the degree of pass-through will be less though still greater than zero. Changes in the real value of the dollar therefore have an impact on the overall mark-up of domestic prices over domestic unit labor costs. These relationships are captured by a distributed lag on current and past percent changes in the real trade-weighted value of the dollar.

A second type of "supply shock" to the price level comes from changes in the real price of oil. Changes in the real price of oil alter the mark-up of prices over unit labor costs by changing the price of an important non-labor input. A distributed lag on the percentage change in the real price of oil is therefore the final component of the inflation equation.[7]

To obtain the augmented autoregressive measure of expected short-term inflation, the inflation equation in the San Francisco model was estimated with two-quarter ahead inflation in the GNP fixed weighted price index as the dependent variable. The sample period is 1958 to 1986. The fitted values of this equation are:

$$\dot{p}^e = .168 - .455U + \sum_{i=0}^{10} a_i\dot{p}_{-1} + \sum_{i=0}^{3} b_i\dot{POIL}_{-i} + \sum_{i=0}^{5} c_i\dot{EXCH}_{-i} \qquad (4)$$

$$\sum_{i=0}^{10} a_i = 1.0 \qquad \sum_{i=0}^{3} b_i = 0.0289 \qquad \sum_{i=0}^{5} c_i = -0.114$$

where $\dot{p}^e$ = two quarter ahead inflation rate
U = civilian unemployment rate, adjusted for demographic changes

$\dot{p}$ = quarterly inflation rate
$\dot{POIL}$ = rate of change in real price of oil
$\dot{EXCH}$ = rate of change in real value of the dollar

Unlike the purely autoregressive measure, this augmented autoregressive forecasting equation allows economic agents to take into account other information in forming expectations of inflation. This measure is based on relevant theory describing the dynamics of the inflationary process. It therefore contains information that is missing from the simple adaptive expectations hypothesis.

It also corrects a possible deficiency of the adaptive expectations hypothesis. Forecasts from the adaptive expectations model systematically underpredict inflation when it is rising and overpredict it when it is falling. In contrast, the augmented measure does not lead to systematic over- or underprediction. Therefore, it meets the condition of unbiased forecasts that is basic to the idea of rational expectations.

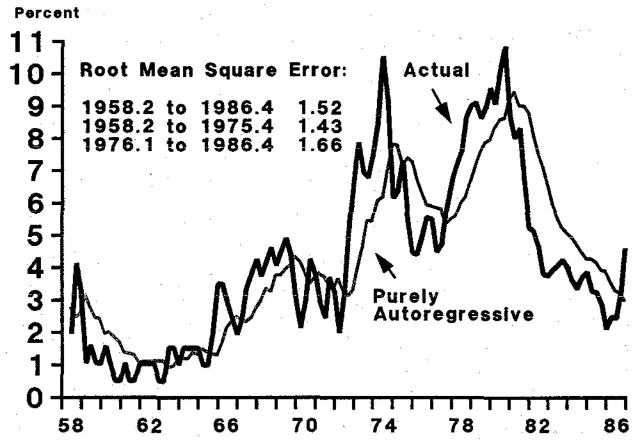
The augmented autoregressive forecasting equation produces unbiased forecasts because it is based on an expectations-augmented Phillips curve. When the unemployment rate is at its full employment level, it contributes nothing to current inflation. Current inflation is then the same as past inflation, except as it is disturbed by shocks to the price level from oil or the dollar. But when the unemployment rate is below full employment and current inflation exceeds past inflation, the deviation of the unemployment rate from its full employment level explains the extent to which current inflation exceeds past inflation.

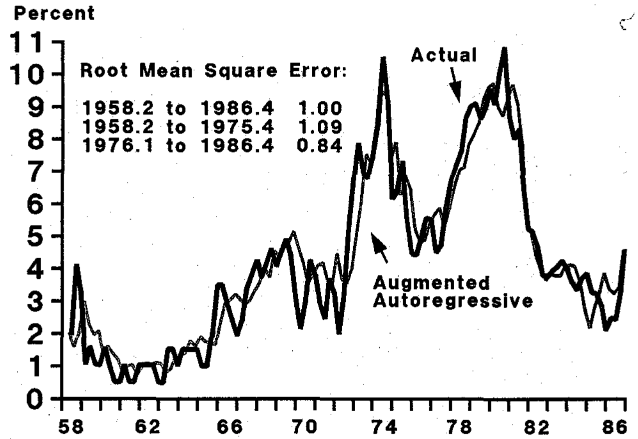
The augmented autoregressive forecasting equation omits growth in the money supply—a variable that most proponents of rational expectations think is important in the formation of expectations of inflation. Since inflation generally is believed by economists to be a monetary phenomenon, particularly in the long run, Rutledge (1974) and others have argued that past movements in the stock of money should be the primary determinant of inflationary expectations. But the augmented autoregressive equation already describes the dynamic process by which monetary impulses are transmitted to prices, and nothing is added by including money growth.[8]

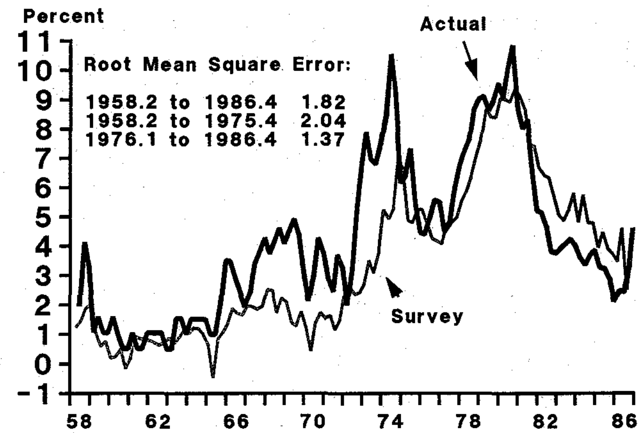
Survey Measure

A survey measure of expected inflation might provide even better forecasts of inflation, as it could incorporate projected values of any and all determinants of inflation that market participants might think are important. In particular, it could include information on current and past

Chart 1
Alternative Measures of Expected Inflation*







* Expected two quarters ahead

values of economic variables that are omitted from the augmented autoregressive measure and judgments about the likely stance of monetary policy and other government actions in the future.

For a survey measure of two quarter ahead expectations, we use the NBER-ASA survey for the period from the fourth quarter of 1968 to the fourth quarter of 1986 and the Livingston survey for the years not covered by the NBER-ASA survey. Both these surveys cover forecasts of professional business economists that were available to the public.[9] The NBER-ASA survey is preferred for our purposes since it gauges inflation by a GNP index, while the Livingston survey refers to consumer prices. Movements in consumer prices and GNP prices have tended to diverge the most when there have been supply shocks from oil, food, or the dollar. Consequently, little is lost by using the Livingston survey for the relatively tranquil period through the end of the 1960s. Moreover, we have adjusted the Livingston survey to remove systematic differences between the trend rate of inflation in the consumer price index and prices in the GNP index.[10]

Ironically, extensive analysis of the NBER-ASA survey by Zarnowitz (1985) and the Livingston survey by Carlson (1977), Pearce (1979), and Figlewski and Wachter (1981) shows that the inflation forecasts of professionals are not fully rational and instead, display systematic bias in their forecast errors, the more so the longer the term of the forecast. As shown by Zarnowitz (1985), however, their forecasts of most other variables have come considerably closer to satisfying the criterion of rationality.[11]

Also, the inflation forecasts of these surveys generally have been no more accurate than the forecasts of either the purely autoregressive or augmented autoregressive measures of expectations. Chart 1 shows the forecasts of these three measures of expected inflation compared with the actual inflation rate realized for two quarters ahead from 1958 to 1986. The root-mean-squared forecasting errors of the survey, purely autoregressive, and augmented autoregressive measures of inflationary expectations for the period 1958.2 to 1986.4 are 1.82, 1.52, and 1.00 percentage points, respectively. The purely autoregressive measure systematically lags behind actual inflation due to the way it is constructed. But its forecast errors in the period since 1958 actually are smaller than those of the survey measure, and the errors of the augmented autoregressive measure of inflationary expectations are smaller still.

Although the survey measure chronically underestimated inflation through the mid-1970s, the professional forecasters covered by the surveys became more sophisticated over time. Despite continued shocks from oil and the dollar, the root-mean-squared error of their forecasts dropped from 2.04 percentage points in the period 1958.2–1975.4 to 1.37 percentage points in 1976.1–1986.4. As a result, their forecasting error dropped below the 1.66 percentage point error of the purely autoregressive forecast in the second period, but still was considerably larger than the 0.84 percentage error of the augmented autoregressive forecast.

II. Short-Term Inflationary Expectations and Consumer Durables

In this section, the San Francisco econometric model's equation for expenditures on consumer durables is used to determine which of the three alternative measures of expected inflation best represents the short-term inflationary expectations of households. In this equation, expenditures on consumer durables follow a stock adjustment process. The desired stock of durables is determined, in part, by a real short-term interest rate. To obtain this rate, the measures of short-term inflationary expectations derived in the preceding section are used. The best measure of household inflationary expectations ought to generate a measure of the real interest rate that gives the best fit to the durables equation.

In the San Francisco model, the desired stock of durables depends upon the level of permanent income.[12] The adaptive expectations hypothesis is used to measure permanent income, so that permanent income is a geometrically declining distributed lag on disposable income. Transitory income, which is the difference between current income and permanent income, is allocated to either real or financial assets, including consumer durables. A freely fitted distributed lag on disposable income captures both of these effects. If the speed of adjustment of the actual to the desired stock of durables is slow compared with the rate of replacement, then the stock of consumer durables in the previous period enters the equation with a positive sign.

Finally, an important determinant of the relative price of durables is the real short-term rate of interest. We use the real 6-month commercial paper rate to measure this. The effect of the real interest rate on the desired stock of durables is captured by a distributed lag on the product of the real interest rate and permanent disposable income, which allows the absolute effect of a change in the real interest rate on real expenditures to increase with the level of real income. Thus, the form of the equation that is estimated is:[13]

$$CD = a + \sum_{i=0}^{3} b_i YD_{-1} - \sum_{i=1}^{2} c_i(i - \dot{p}^e)_{-i} YD^p_{-i} + d_i K_{-1} \quad (5)$$

where CD = real expenditures on consumer durables
YD = real disposable personal income
i = nominal 6-month commercial paper rate
$\dot{p}^e$ = measure of two quarter-ahead expected inflation
YD^P = permanent real disposable personal income
K = real stock of consumer durables

The estimated standard errors of this equation, using the three alternative measures of two quarter-ahead expectations of inflation, are shown in Table 1. Since the survey forecast became considerably more accurate after the mid-1970s, the sample period was split into two sub-periods of 1958.2–1975.4 and 1976.1–1986.4. In the first sub-period, the standard errors associated with the three alternative measures of expected inflation are quite close to one another. Household expectations of inflation in this period are not measured well by any of the three alternative measures, given the maintained hypothesis that consumer expenditures on durables are affected by expected inflation. Otherwise, one of the three measures would have fit the data distinctly better than the others, given the strong differences between them in this period.

In the second sub-period, household short-term expectations of inflation are most closely represented by the purely autoregressive measure. The purely autoregressive measure of expected inflation produces the lowest standard error for the consumer durables equation of the three alternative measures of expected inflation. There is a relatively small difference from the survey measure and a much larger difference from the augmented autoregressive measure. The relatively small difference between the closeness of fit of the purely autoregressive and survey measures in this period is due to the high correlation between their movements, as shown in Chart 1. The forecast errors of these two measures also are similar in the second sub-period. Apparently, the survey measure does not contain much extra information that households could have used. Thus, households' expectations of inflation in recent years appear to have been basically adaptive.

In an important work, Lucas (1976) has criticized the use of autoregressive expectations in econometric modeling. Lucas argued that agents form expectations rationally, and not adaptively, and as a result, the relationship beween past inflation and expected inflation would change if economic agents recognize that a significant shift in monetary policy is taking place. Therefore, an additional test of whether household expectations are adaptive is whether the consumer durables equation that uses autoregressive expectations of inflation is stable in a period of significant change in monetary policy.

One such period is the post-October 1979 disinflation in the U.S. economy. At the beginning of this period, a technical change in the Fed's operating procedures both signaled the Federal Reserve's commitment to lower inflation and facilitated the achievement of the desired reduction in monetary growth. The policy achieved its objective. Inflation in the GNP price index dropped from a 9.8 percent rate in 1980 to 2.3 percent in 1986. If any recent change in monetary policy could have altered expectations of inflation independently of the past history of inflation, this would appear to be it. Not only were there indications of a new resolve on the part of the Federal Reserve, but the Reagan Administration was highly supportive of a disinflationary policy. In addition, as Huizinga and Mishkin (1986) recently have shown, the post-October 1979 period

Table 1

Estimated Standard Errors of Consumer Durables Equation

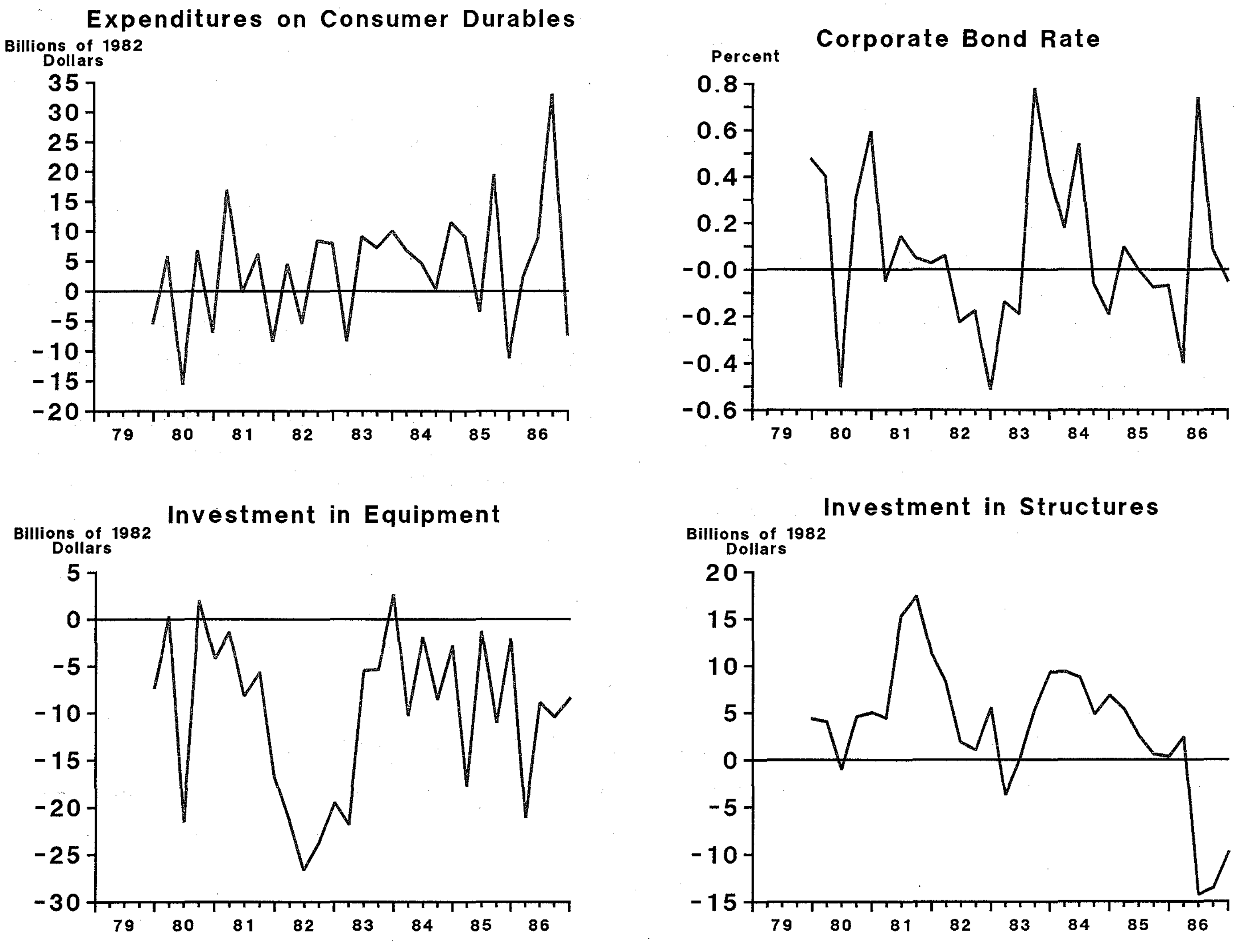
Sector	Model of Expected Inflation		
Expenditures on Consumer Durables (Billions of 1982 Dollars)	Purely Autoregressive	Augmented Autoregressive	Survey
1958.2–1975.4	4.47	4.41	4.37
1976.1–1986.4	6.59	7.60	6.81

meets the technical criteria for a "regime shift" in monetary policy.

According to the Lucas critique, this shift in the monetary policy regime should have helped to bring down expectations of inflation faster than usual. As a result, an autoregressive measure of expected inflation would tend to overestimate true expectations and therefore underestimate true real interest rates. A consumer durables equation using this estimate of real interest rates would therefore tend to overpredict spending.

As shown in Chart 2, however, there is no systematic tendency for the consumer durables equation to overpredict spending in the period after October 1979 even when the autoregressive measure of inflationary expectations is used. Moreover, as shown in Table 2, an F test rejects the hypothesis of instability in the coefficients of the consumer durables equation, suggesting that no shift in the formation of expectations occurred.[14] This is contrary to the prediction of the Lucas critique. Not only do household expectations of inflation appear to be basically adaptive, but their estimated structure continued to hold up in a period of significant policy change.

Chart 2
Out-of-Sample Forecasting Errors*



* Actual less predicted

Table 2

F Tests for Stability

Equation	Model of Expectation Formation	Sub-Periods	Critical F Values 1%	Critical F Values 5%	F Statistic
Expenditures on Consumer Durables	Purely Autoregressive	1958.2–1979.3 1979.4–1986.4	1.92	2.51	1.33
Corporate Bond Rate	Augmented-Autoregressive	1961.4–1979.3 1979.4–1986.4	1.77	2.24	2.86
Investment in Equipment	Purely Autoregressive	1964.1–1979.3 1979.4–1986.4	2.21	3.04	1.74
Investment in Structures	Purely Autoregressive	1964.1–1979.3 1979.4–1986.4	2.06	2.75	2.75

III. Short-Term and Long-Term Inflationary Expectations and the Bond Rate

In this section, three alternative measures of expected long-term inflation are developed within the context of the equation in the San Francisco model that explains the Aaa corporate bond rate. This equation is based on the "preferred habitat" theory of the term structure of interest rates developed by Modigliani and his colleagues. This approach synthesizes the market segmentation and expectational theories of the term structure of interest rates. In this approach, the long-term rate is equal to the average of current and expected short-term rates, modified by a risk premium reflecting the relative preferences of the two sides of the market for long versus short securities. In the original statement by Modigliani and Sutch (1966), expectations are formed autoregressively, with the past history of nominal short-term rates being used to forecast expected future short rates. In an improved version by Modigliani and Shiller (1973), expectations continue to be formed autoregressively, but the possibility that the process of expectation formation may differ for the real and inflationary components of future short-term rates is allowed.

The Modigliani and Shiller model for the long-term bond rate is:

$$i_l = K + \sum_{i=0}^{11} w_i(i_s - \dot{p})_{-i} + \sum_{i=0}^{11} v_i\dot{p}_i \qquad (6)$$

where i_l = Aaa corporate bond rate
i_s = 6-month commmercial paper rate
$\dot{p}$ = quarterly inflation rate
K = constant risk premium

In this model, expectations of future real short-term rates are formed autoregressively on the basis of a weighted average of current and past real short-term rates, with weights w_i. Moreover, short-term inflationary expectations in current and past real rates are modeled in the simplest possible autoregressive way. They are equal to the inflation rate at issuance of the short-term security, implying no expected change in inflation over the short-term horizon. Expected inflation premiums in future short rates —or equivalently, the long-term expectation of future inflation —also are measured autoregressively, but with weights v_i on current and past rates of inflation. Collecting the inflation terms, the equation that Modigliani and Shiller estimate for the bond rate then becomes:

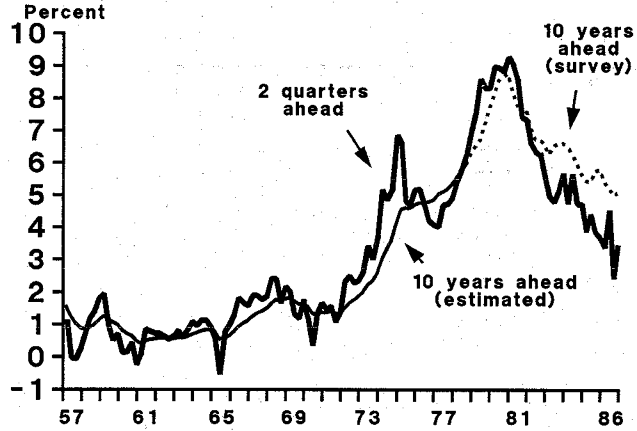
$$i_l = K + \sum_{i=0}^{11}[w \cdot i_s]_{-i} + \sum_{i=0}^{11}[(v-w)\dot{p}]_{-1} \qquad (7)$$

We use this Modigliani and Shiller equation (7) for the purely autoregressive representation of inflationary expectations in the bond market.[15] Not only are expectations of inflation in current and past short rates formed autoregressively, but so also are expectations of the two components of future short rates.

More information would be incorporated if the augmented autoregressive measure of short-term expectations of inflation developed in the first section of this paper were used to calculate the current and past short-term real rates in equation (6). Thus, for the augmented autoregressive representation of expectations in the bond market, we substitute the augmented autoregressive measure of current and past short-term real rates for $i_s - \dot{p}$ in equation (6). Since current and past inflation represents current and past short-term expectations of inflation in the Modigliani and Shiller approach, the long-term expectation of inflation actually is formed on the basis of current and past short-term expectations of inflation. Therefore, in the augmented autoregressive representation of expectations, we can substitute the augmented autoregressive measure of short-term expectations for $\dot{p}$ in the rest of equation (6). The augmented autoregressive measures of short-term expectations of inflation can then be collected to form an equivalent of equation (7).

For the model of the bond rate with survey-based measures of expectations, the Livingston and NBER-ASA data were used for expected inflation in current and past short-term real rates and a survey of 10 year-ahead expectations of inflation collected by Richard Hoey of Drexel, Burnham, and Lambert was used for long-term expectations of future inflation. These 2-quarter-ahead and 10-year-ahead survey measures of expected inflation are plotted in Chart 3. Since the Hoey survey of 10-year-ahead expectations does not go back before 1978.4, we estimated the 10-year-ahead expectations for the prior years, based on a geometric lag on the 2-quarter-ahead expectations. Analysis of the two survey measures revealed that short-term and long-term expectations of inflation have a rather well behaved term structure, similar to that assumed in the two autoregressive measures. Thus, it was reasonable to approximate the 10-year-ahead expectations for the period prior to the Hoey survey by means of a geometric lag on 2-quarter-ahead expectations. This geometric lag assumes that long-term expectations of inflation are revised in proportion to the difference between the current short-term expectation of inflation and the previous long-term expectation.[16]

Chart 3
Survey Measures of Expected Inflation



For the survey-based measure of expectations, the bond rate equation was estimated in the form of equation (6), with the survey measure of short-term expectations of inflation incorporated into $i_s - \dot{p}$ and the survey measure of long-term expectations being used for the final term. In contrast, the bond rate equation estimated for the other two measures of expectations takes the form of equation (7), where the measures of short-term expectations of inflation are collected.

The sample period again was split in the mid-1970s. Recall that the forecast errors of the survey measure of short-term expectations of inflation dropped considerably in the second of the sub-periods. Also, remember that the survey measure of long-term expectations of inflation is

Table 3
Estimated Standard Errors of Bond Rate Equation

Sector	Model of Expected Inflation		
Corporate Bond Rate (Percent)	Purely Autoregressive	Augmented Autoregressive	Survey
1961.4–1975.4	.128	.105	.147
1976.1–1986.4	.374	.376	.423

mostly actual data in this period, rather than being estimated through a term structure relation with short-term expectations. Nevertheless, as shown in Table 3, the bond rate equation using the survey measure has distinctly the largest standard errors of any of the three measures of expectations in *both* sub-periods. A partial explanation of the relatively poor fit of the survey measure in the bond rate equation may be that the survey evidence measures *average* rather than *marginal* beliefs. The presence of arbitragers in this market suggests that actions of marginal investors are likely to be much more critical than in other markets.

The augmented autoregressive measure of expected inflation has the lowest standard error in the 1961.4–1975.4 subperiod, and about the same standard error as the purely autoregressive measure in the 1976.1–1986.4 subperiod. Thus, the forecasts of marginal investors appear usually to have incorporated at least some of the extra information contained in the augmented autoregressive measure of expectations. This is true even in the second sub-period when the standard errors of the bond rate equation are about the same for these two measures of expectations. Since the augmented autoregressive measure of expectations contains more information and has a lower forecasting error, the equal standard errors generated by the bond rate equation suggest that market participants used some, but not all, of this extra information in this period.

Once again, we examine the Lucas critique of the adaptive expectations approach by testing for stability of the term-structure equation in the period following the post-October 1979 shift in monetary policy. The Federal Reserve's shift to a disinflationary monetary policy could have produced two opposite effects on the term structure of interest rates. On the one hand, a credible disinflationary policy could produce expectations of a sustained period of tight money in which the real short-term interest rates expected in the relatively near future would rise by more than ordinarily would be explained by the behavior of current and past short-term rates. On the other hand, such a policy also could dampen expectations of inflation, which would reduce the nominal short-term rates expected in the more far distant future due to lower inflationary premiums in interest rates. If the first effect dominates, the term-structure equation would tend to underpredict nominal long-term rates of interest. But if the second effect dominated, overprediction would result. For a bond with a long maturity, the second effect would be more likely to dominate if inflationary expectations were significantly affected.

Chart 2 shows out-of-sample forecast errors of the equation for the Aaa corporate bond rate for the post-October 1979 period. The augmented autoregressive measure of inflationary expectations was used since it best fits the data for the entire sample period. From 1979.4 through 1982.1, the forecast errors (actual minus predicted) are positive for eight out of the ten quarters, suggesting that there was an upward shift in expectations of future *real* short-term interest rates due to the shift to a disinflationary policy. This shift is strong enough that an F test for the whole period from October 1979 through the end of 1986 rejects stability at the 5 percent level, as shown in Table 2. But the effect was only temporary. After the first quarter of 1981, forecast errors are neither predominantly positive nor negative.

Thus, in the period immediately after October 1979, there is evidence of an upward shift in expectations of future real short-term interest rates. Any response of an expected decline in inflationary premiums was not strong enough to offset this, even though the Aaa corporate bond has a long maturity. Moreover, after 1982 when real interest rates had dropped, there is no predominance of negative forecast errors, as would have been the case if the augmented autoregressive forecasts were overpredicting the market's expectation of future inflation. Therefore, although there is evidence to suggest that bond market participants believed tight monetary policy would affect real interest rates in a manner that could not have been predicted by extrapolation from past history, this belief does not appear to have extended to their expectations of disinflation in wages and prices.[17]

IV. Long-Term Inflationary Expectations and Business Fixed Investment

Alternative measures of longer term expectations of inflation are evaluated next within the context of the real after-tax bond rate in the San Francisco econometric model's equations for business investment in equipment and structures. These equations follow the neoclassical theory of investment developed by Jorgenson (1963) and Hall and Jorgenson (1967). In this approach, capital is a substitute for other factors of production, and firms combine capital with these other factors so as to minimize costs and maximize profits.

These investment equations follow a stock-adjustment process in which the desired stock of capital is determined by final sales and the real rental cost of capital. Lag weights are imposed according to the lags between capital appropriations and expenditures, as estimated by Almon (1965). A 2-quarter time lag between investment decisions and capital appropriations is assumed. In addition, we allow investment plans to be cancelled or expanded after the initial appropriations process when sales turn out to be greater or less than originally anticipated. This is captured by adding a variable equal to the difference between sales lagged one quarter and expected sales, as measured by a distributed lag (with weights the same as between appropriations and capital expenditures) on past sales, adjusted for normal growth. Thus, the form of these equations is:[18]

$$
\begin{aligned}
I = b_0 + b_1 \sum_{i=2}^{9} (w \cdot FS)_{-i} + b_2 \sum_{i=2}^{9} (w \cdot RC \cdot FS)_{-i} \\
- b_3 \sum_{i=3}^{10} (w \cdot K)_{-i} \\
+ b_4 [FS_{-1} - \sum_{i=3}^{10} w_{-i} \cdot FS_{-i} (1+T)^{i-1}]. \qquad (8)
\end{aligned}
$$

where I = real investment in equipment or structures
FS = real final sales
RC = real rental cost of capital
K = real stock of capital at end of quarter
w = lag weights

The real rental cost of capital can be shown to be equal to:[19]

$$RC = T(i - \dot{p} + d) \qquad (9)$$

where i = nominal long-term interest rate
$\dot{p}$ = long-term expectation of inflation
d = physical rate of depreciation of capital
T = term that depends on corporate income tax, any investment tax credits, and allowable depreciation

The real rental cost of capital is a function of the real rate of interest, $i - \dot{p}$, as well as the physical rate of depreciation and taxes. For long lived capital investment, such as plant and equipment, the relevant real rate of interest is a long-term one. We calculate this as a weighted average of the real cost of debt and equity capital, with weights of ⅓ and ⅔, respectively, equal to their average values over the past two decades. The real cost of equity capital is measured by a distributed lag on earnings per dollar of share price. The real cost of debt is calculated on an after-tax basis. Since interest cost is deductible from earnings, every dollar of interest cost reduces corporate taxes by the amount of the corporate tax rate.

Equations for business investment in equipment and structures were estimated with three alternative measures of the long-term expectations of inflation that enter into the real after-tax Aaa bond rate in the rental cost of capital. The autoregressive measure of long-term inflation expectations is a purely adaptive one calculated as a geometrically declining weighted average of past inflation, where the estimated rate of decline is slower than in the adaptive measure of two quarter-ahead expectations.[20] This adaptive measure is subtracted from the nominal after-tax Aaa bond rate to obtain the purely autoregressive measure of the real after-tax bond rate.

The augmented autoregressive measure of the real after-tax bond rate is obtained from a weighted average of expected real after-tax short rates, plus a risk premium, calculated from the first two terms of equation (6). Specifically, this measure of the real after-tax bond rate is calculated by weighting the augmented autoregressive measure of current and past real after-tax short-term rates with estimated weights, w_i. To this we add the tax-adjusted value of the estimated risk premium, K, to obtain the augmented autoregressive measure of the real after-tax bond rate.

Finally, the survey measure of long-term expectations of inflation that we use is simply the 10-year-ahead Hoey survey, which was extrapolated backward on the basis of the estimated relationship between the short- and long-term surveys, as discussed in Section III. This survey measure is subtracted from the nominal after-tax Aaa bond rate to obtain the survey measure of the real after-tax bond rate.

The standard errors of the model's equations for investment in equipment and structures using the three alternative measures of long-term expectations of inflation are presented in Table 4. The standard errors for the survey and adaptive measures are about equally low, suggesting that economic agents who make long-term capital investments form their long-term expectations of inflation adaptively. The augmented autoregressive measure of long-term expectations of inflation gives distinctly larger standard errors in both equipment and structures than do the other two measures. Even though this measure incorporates information that is used to some extent by arbitragers in the bond market, there is no indication that this information also is utilized by economic agents undertaking business investment in equipment and structures.

Turning to the question of the stability of the structure of these adaptive expectations, out-of-sample forecast errors for these investment equations in the period after October 1979 are shown in Chart 2. In the case of investment in

Table 4
Estimated Standard Errors of Investment Equations

Sector	Model of Expected Inflation		
Nonresidential Fixed Investment (Billions of 1982 Dollars)	Purely Autoregressive	Augmented Autoregressive	Survey
Equipment			
1964.1–1986.4	5.19	5.47	5.12
Structures			
1964.1–1986.4	2.82	2.99	2.81

equipment, there is a general tendency for the equation to overpredict, as would occur if the real bond rate were being understated due to overpredictions of inflation associated with adaptively formed expectations. However, the largest of these errors occur during the 1981–82 recession when the equation appears to be prone to missing a turning point. Any errors from an adaptive mismeasurement of long-term inflationary expectations likely would have died out more gradually than these do. Also, an F test cannot reject stability of the equipment equation, as indicated in Table 2. Thus, the forecast errors of the equipment equation are not atypically large, and they appear to be more closely related to business cycle factors than to the mismeasurement of expected inflation.

The equation for investment in structures tends to underpredict in the post-October 1979 period, which is the opposite of what would be expected from an adaptive mismeasurement of expected inflation. Also, the F test indicates stability. Taken together, the results for investment in equipment and structures do not suggest that the Federal Reserve's shift to a disinflationary monetary policy had any significant direct effect on the formation of long-term expectations of inflation over and above the adaptive response of market participants to current and past inflation.

V. Summary and Conclusions

In this article, we have evaluated the explanatory power of alternative measures of expected inflation in the investment sector of a structural econometric model of the U.S. economy. Previous research has indicated that purely autoregressive models of expected inflation fit labor market data about as well as survey measures that might capture any additional information used by market participants in the formation of expectations.[21] These studies also have found that an autoregressive representation of inflationary expectations in the labor market generally is robust to sharp changes, such as the acceleration of inflation in the 1970s and the post-1981 disinflation in the United States.[22] Likewise, in this study, we have found that the inflationary expectations of participants in the investment sector of the economy generally have these same characteristics.

The short-term expectations of inflation reflected in households' purchases of consumer durables are as well represented by a purely autoregressive measure based on past inflation alone as by a survey measure, suggesting that actual expectations are basically adaptive.

We also examined alternative measures of long-term expectations of inflation in the context of business decisions with respect to long-lived capital investment. These long-term expectations of inflation are about equally well represented by a purely autoregressive measure and a survey measure, suggesting that here too, actual expectations of inflation are basically adaptive.

In contrast, investors who arbitrage between short-term and long-term securities appear to take into account additional information that is not captured by either a purely autoregressive or a survey measure of expected inflation. This additional information is at least partly captured by an augmented autoregressive measure containing not only past inflation, but also current unemployment and current and past changes in the real price of oil and the real value of the dollar.

Since neither the purely autoregressive nor the augmented autoregressive measure of expected inflation contains any forecast of future monetary policy, both might be poor estimates of inflationary expectations when changes occur in monetary policy that potentially might change relationships between future inflation and the current and past values of inflation or other variables—the Lucas critique. An important example of such a change is the disinflation that was produced by a change in U.S. monetary policy in October 1979. But stability tests on the equations for spending on consumer durables, the long-term bond rate, and business fixed investment do not indicate that the Federal Reserve's October 1979 shift in monetary policy significantly affected the formation of inflationary expectations, either short- or long-term, in any direct way. Although there is evidence that this policy temporarily affected expectations of future *real* interest rates, its influence does not appear to have extended in any significant way to the formation of expectations of inflation premiums in future nominal interest rates.

In conclusion, inflationary expectations in the U.S. economy appear close to being purely adaptive, formed simply by extrapolating from past inflation. Moreover, autoregressive representations of inflationary expectations appear quite stable, even in the face of major changes in monetary policy. Contrary to the Lucas critique, conventional macro-econometric models that contain relatively backward looking and slowly adjusting autoregressive expectations of inflation can be expected to generate reasonably accurate forecasts of the economy's response to changes in monetary policy.[23] This response includes a significant short-run effect on real interest rates, output, and employment, but one that diminishes over several years so that in the long run only inflation is affected.

ENDNOTES

1. An earlier version of this structural macro-econometric model, described in Throop (1984b), contained only the aggregate demand side of the economy. The current version of the model includes additional equations for the inflation rate, the unemployment rate, the share of disposable income in GNP, and the demand for money. A complete description of the current version is forthcoming in the *Working Papers in Applied Economic Theory and Econometrics* series of this Bank, and an article summarizing its dynamic properties will be published shortly in the *Economic Review.*

2. See, for example, Friedman (1957) and Nerlove (1958).

3. The parameter α was estimated from equations in the model, rather than from the actual two quarter-ahead inflation rate, because we want the best representation of the public's expectation of inflation. This is not necessarily the same thing as the best forecast of inflation.

4. This relationship between the speed of adjustment and the degree of excess demand has been advanced by Samuelson (1974), Baumol (1959), Reder (1947), and Lipsey (1960), among others.

5. According to an alternative view, markets always are in equilibrium, and movements in employment and output are due solely to misperceptions of future inflation. The equilibrium view, which was proposed in an early form by Irving Fisher (1926), underpins the "new" classical macroeconomics of Lucas (1972, 1975) and Sargent (1976). In the equilibrium view, price and wage changes cause output and employment changes, and so would normally tend to precede them; whereas in the more conventional view, causation runs in the reverse direction and with the opposite lags. The available evidence suggests that changes in employment and output generally tend to precede the price and wage changes associated with them, supporting the conventional view. See Gordon (1980), Laidler (1978), Nelson (1981), Okun (1980), and also the recent survey article by Kniesner and Goldsmith (1987) on this subject.

6. The civilian unemployment rate is adjusted for the effects of changes in the full employment rate of unemployment due to changes in the demographic composition of the labor force. This is done by subtracting from the civilian unemployment rate a measure of variation in the unemployment rate due to demographics that has been calculated by the Congressional Budget Office (1987). Partly as a result of these demographic changes, Medoff and Abraham (1982) find that in the United States the vacancy rate is a more accurate measure of excess demand than the unemployment rate, but the Bureau of Labor Statistics has collected vacancy data experimentally for only a relatively brief period. Better data on vacancies is available in the U.K., where a stable inverse relationship between vacancies and unemployment has been observed. See Dicks-Mireaux and Dow (1958, 1959).

7. Our treatment of the role of the value of the dollar and the price of oil in the inflation process draws on the earlier work of McElhattan (1985). A useful survey of previous studies on the impact of the value of the dollar on prices is Hooper and Lowry (1979). For more recent evidence, see Woo (1984).

8. The relationship between inflation and M1 growth deteriorated badly after 1982. Compare Karnosky (1976) with Judd and Trehan (1987). But even before 1982, inflation could be predicted as well by an augmented Phillips curve that describes the dynamics of the process by which monetary impulses are transmitted to prices as by money itself, as shown by Throop (1984). Moreover, as

Wachter (1976) has demonstrated, past money growth does not contribute any more to an explanation of inflation than past inflation does when either one is included in an augmented Phillips curve.

Some recent research has emphasized the distinction between the effects of anticipated and unanticipated money growth on prices. For example, Barro (1987) argues that anticipated money growth has a one-to-one contemporaneous effect on prices, while deviations in output growth from trend are due only to unanticipated money growth. However, the notion of an immediate response in prices to anticipated changes in money makes sense only in the case of auction markets where there is no inertia in price adjustment. It would be difficult to characterize U.S. labor markets and many product markets in such terms. Studies which dispute the importance of the distinction between anticipated and unanticipated money growth include Mishkin (1982) and Gordon (1982).

9. The NBER-ASA survey is published periodically by the Survey Research Center of the University of Michigan in *Economic Outlook USA*. Complete data tapes are maintained by the National Bureau of Economic Research. We used the Livingston survey as adjusted by Carlson's (1977) method and maintained by the Federal Reserve Bank of Philadelphia.

10. Actually, the NBER-ASA survey uses the GNP implicit price deflator, rather than the GNP fixed-weighted price index used in our structural econometric model. But each of the survey measures of expectations was adjusted to remove any systematic difference between their trend rates of inflation and the trend rate of change in the GNP fixed-weighted price index. This was done by subtracting from each the average difference between two quarter-ahead inflation in its concept and two quarter-ahead inflation in the GNP fixed-weighted price index in neighboring quarters.

11. Zarnowitz (1985) shows that the NBER-ASA survey is not free of systematic bias, the more so the longer the term of the forecast. A lack of randomness in the errors from the Livingston forecast is confirmed by Carlson (1977). Pearce (1979) has found that univariate time series models yield better inflation predictions than the Livingston survey. In addition, Figlewski and Wachtel (1981) have examined the individual forecasts contained within the Livingston sample. They conclude that the condition of unbiasedness can easily be rejected and that current forecast errors can be explained by past forecast errors. Webb (1987) points out a number of pitfalls in using *ex post* tests of statistical bias to infer the *ex ante* rationality of forecasts. Even so, the difference between the accuracy of survey forecasts of inflation and the accuracy of their other forecasts is striking.

12. The permanent income hypothesis of Friedman (1957) was used in early versions of the San Francisco econometric model. Studies applying this approach to consumer durables include Juster and Wachtel (1972) and Darby (1975). In the forthcoming version, however, the consumption function is based on the life-cycle model of Ando and Modigliani (1963).

13. Permanent disposable income was calculated as a 16 quarter geometric lag on current disposable income, adjusted for the trend in income:

$$YD^{P} = \sum_{i=0}^{15} \alpha(1-\alpha)^{i}(1+T)^{i}YD_{-i}.$$

The parameter α was estimated at 0.5. Also, dummy variables were included to capture the effects of the Carter administration's credit controls in the period 1980.2 through 1980.4.

Until the 1986 reform of the tax law, interest paid on the purchases of consumer durables was deductible from taxable income for households who itemized. Thus, the real *after-tax* rate of interest is the theoretically correct measure of the cost of capital for these individuals, as well as households whose alternative is investment in financial assets. The consumer durables equation was first estimated with the real after-tax commercial paper rate, using the Barro and Shahasakul (1983) estimates of the average marginal tax rate of households. However, when alternative weights between zero and one were placed on the tax rate, the best fitting equation was the one with a zero weight. Therefore, the real pre-tax commercial paper rate was chosen for the equation.

14. In Table 2, the variables were all transformed according to the estimated serial correlation coefficient for the full period. F tests were then performed on the residuals from the estimated equations that use these transformed variables. This procedure avoids a rejection of stability simply because of instability in the error pattern, as opposed to a shift in the structural equation itself.

15. An additional component of the term structure equation that we estimated, which for simplicity is not discussed in the text, allows for the fact that the average effective maturity, or "duration," of a coupon bond depends upon the level of interest rates. When interest rates are high, the duration of newly issued bonds is shorter because a larger portion of the total payment of interest and principal occurs relatively early. Conversely, when interest rates are low, the duration of a bond becomes longer. Thus, the lags on past interest rates in an autoregressive model of expectations should be shorter the shorter is the average effective maturity of the bond. The term structure equation captures this duration effect by adding a term formed by multiplying a distributed lag on the commercial paper rate by the recent average level of the commercial paper rate, with the sum of the weights on the lagged values of the commercial paper being constrained to zero. The estimated coefficients on these lagged values of the commercial paper rate are first positive and then negative. Thus, the mean length of the overall lag distribution on the commercial paper rate shortens when the level of interest rates rises, confirming the existence of a duration effect. For further discussion of the duration effect, see Van Horne (1984).

We also experimented with the assumption of a greater degree of rationality in expectations by including the change in the ratio of the federal high employment budget to high employment GNP from the last four quarters to four quarters ahead as an additional variable. Information is generally available about what the budget will look like in the coming year, and a rational market should incorporate this information into its view of where short-term interest rates in the future will be, and therefore what bond yields should be today. However, even when the test for such an effect was restricted to the period of large and growing budget deficits under the Reagan administration, no statistically significant impact of expected changes in the budget deficit could be detected.

16. The best fitting geometric lag has a speed of adjustment, equal to the coefficient α in equation (3), of 0.17.

17. Blanchard (1984) reaches a similar conclusion.

18. The equation for structures also contains a distributed lag on the real price of oil. An important component of investment in structures is oil drilling, which responds positively to its price.

19. For a derivation, see Hall and Jorgenson (1967) or Throop (1984b).

20. The best fitting geometric lag in equipment and structures has a speed of adjustment, equal to the coefficient α in equation (3), of 0.05.

21. McNess (1979) compared an expectations-augmented Phillips curve using an autoregressive measure of expected inflation with an alternative version using the survey measure collected by Joseph Livingston, a columnist with the *Philadelphia Inquirer.* Kaufman and Woglom (1984) perform a similar test on union wages using microeconomic data and conclude that their data "do not provide strong support to allow us to reject the hypothesis that inflationary expectations are backward looking."

22. Blanchard (1984), Englander and Los (1983), and Perry (1983) found that expectations-augmented Phillips curves with autoregressive expectations were stable in face of the sharp disinflation after 1981. An earlier study demonstrating similar stability in the 1970s is Smaistrla and Throop (1980).

23. This conclusion holds only for the time periods and policies in this and other studies cited—basically post-World War II U.S. experience. Although there has been a significant amount of variation in inflation in the U.S. economy during this period, extreme variability could cause an autoregressive model of the formation of inflationary expectations to break down. Thus, for example, when comparing countries with vastly different variability in inflation rates, Lucas (1973) finds that the short-run trade-off between inflation and unemployment tends to steepen in those countries where the variability in inflation is greater. A stable autoregressive structure of inflationary expectations, therefore, would not hold up across this range of experience. Similarly, Sargent (1982) finds that in cases where hyperinflations caused by the monetization of government debt have been ended by the creation of an independent central bank and a simultaneous alteration in the fiscal policy regime, inflations were ended quickly and with little adverse effect on output and employment. In these instances, extreme changes in policy and institutions caused an abrupt shift in inflationary expectations that would be inconsistent with a stable autoregressive structure of expectations.

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